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RESEARCH AND TECHNOLOGY ADVISORY COUNCIL REPORT

TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THRUSTS IN AERONAUTICS FOR THE 1980's

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RTAC Report
August 2, 1972

RESEARCH AND TECHNOLOGY ADVISORY COUNCIL REPORT

TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THRUSTS IN AERONAUTICS FOR THE 1980'S

Date: August 2, 1972

Approved by: Richard E. Horner

Richard E. Horner
Chairman, Research
and Technology
Advisory Council

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: R-1

MAR 2 6 1973

To Recipient:

The attached report, "Thrusts in Aeronautics for the 1980's", was prepared by a senior advisory group to NASA, the Research and Technology Advisory Council (RTAC).

The Council is made up of representatives from non-NASA government, universities, NASA, non-profit organizations, and industry. It was established to advise NASA's senior management in the area of aeronautics and space research and technology. The Council studies issues, pinpoints critical problems, determines gaps in needed technology, points out desirable goals and objectives, summarizes the state-of-the-art, assesses on-going work, and makes recommendations to help NASA plan and carry out a program of greatest benefit to the Nation.

The report was prepared at the request of the Deputy Administrator of NASA. It is not an official NASA publication. It is a working type paper designed to help define the technological efforts in aeronautics that should be carried out in the 1970's in order to be ready for the potential programs of the 1980's. NASA will use the document as a source of information from national experts in the area of aeronautics technology and consider it during Agency planning for future areas of emphasis.

It is hoped you will find the document informative in view of your interest in aeronautics.

Sincerely,

Roy P. Jackson
Associate Administrator for
Aeronautics and Space Technology

August 2, 1972

Dr. George M. Low
Deputy Administrator
Office of the Administrator
NASA Headquarters
Washington, D.C. 20546

Dear Dr. Low:

In your letter of January 10, 1972, you requested that the Research and Technology Advisory Council provide recommendations to NASA on what we consider should be the major thrusts in aeronautics for the 1980's. You also asked that we identify the technologies that NASA should be concentrating on in the 1970's in order to meet those major thrusts.

Our approach to this task was in three steps. First, I solicited the initial views of the Council. These views were then passed on to an Ad Hoc Panel which was appointed to consider these as well as additional views. The Panel did a thorough job. They discussed the subject with NASA Centers and Headquarters; DOT; the Air Force, Navy, and Army and then consolidated these views into a report. The final step was to circulate the Panel's report to the Council members for their comments.

The Panel report, updated to reflect the concensus of the Council, is attached as our report to you. There were minority opinions expressed by two of the Council members, and they are attached to complete your information. Each felt there was too great an emphasis on the hypersonic transport. One also felt the same about the supersonic transport.

I hope the Council has responded in a satisfactory manner to your request.

Sincerely,

Richard E. Horner

Attachment

cc: R/R. Jackson

LOCKHEED AIRCRAFT CORPORATION
BURBANK, CALIFORNIA 91503

RONALD SMELT
VICE PRESIDENT
CHIEF SCIENTIST

June 14, 1972

Mr. Richard E. Horner
Chairman, Research and Technology
Advisory Council
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Dick:

The enclosed report, "Thrusts in Aeronautics for the 1980's," represents the formal recommendations of the ad hoc panel which you set up at the Council's last meeting to study the subject. The panel has had the advantage of a large number of individual inputs by letter from members of the Council and of its Advisory Committees. The inputs from members of the Committee on Aeronautics have been particularly valuable.

In addition, the panel has had the advantage of a number of discussions with NASA staff at NASA Headquarters and at the Langley, Lewis and Ames Centers. I believe that both panel members and NASA staff found these discussions to be extremely stimulating and valuable in clarifying the technological possibilities over the next few years. Indeed, they ranged well beyond the material which is presented in our formal report, and John Sloop has written more detailed reports which give a better feeling of the excitement and stimulation of our discussions.

The panel felt that it was essential to check out our conclusions with the DOD members of your Council, and we owe a considerable debt to these members for their contributions. All three Assistant Secretaries for Research and Development, Grant L. Hansen, Robert A. Frosch and Robert L. Johnson, made themselves available, with their key staff members, to discuss future NASA thrusts in relation to military roles. Your Council members from the DOT, including The Hon. Robert Cannon, also brought us together with their staff for similar discussions.

The panel's recommendations for the two major NASA thrusts of the 1980's are contained in Chapter 3 of the formal report. We feel it necessary, however, to preface our recommendations by a discussion (in Chapter 2) of today's thrusts in aeronautics, which we would expect to continue during the '80's and which follow closely the recommendations of the recent CARD Study. Specifically, we recognize the two major current thrusts as:

a. The "good neighbor" aircraft. acceptable to the community; and
b. Short-haul air transportation, with emphasis on STOL aircraft.

While accepting that these two thrusts will continue into the 1980's, we have identified in Chapter 3 two further thrusts which will become paramount in importance:

a. Higher speed, long-haul transportation, leading inevitably to supersonic, or even hypersonic, transports.
b. The VTOL aircraft, as a natural development of the current STOL thrust, and also as a major DOD requirement for a number of military applications.

Our report discusses these thrusts, and the specific projects or goals supporting them, with the pertinent technological requirements, in somewhat general terms but in accordance with the original request of Dr. George Low. We have also summarized (in Chapter 4) the several other candidates which we discussed but which we did not choose to elevate to the status of a major thrust.

I believe I was particularly fortunate, as Chairman of this panel, to have a group of individuals who dedicated much of their time and effort to discussions and to the writing of sections of our final report. It would be good to have these men available at the Council meeting during which the report is discussed, if you think that this would be appropriate. I assume that in due course you will offer them the Council's thanks for their invaluable contribution.

Sincerely,

R. Smelt

Ronald Smelt

RS:ls

AD HOC PANEL REPORT TO THE

NASA RESEARCH AND TECHNOLOGY ADVISORY COUNCIL

THRUST IN AERONAUTICS FOR THE 1980's

1. Objective and Modus Operandi of RTAC Ad Hoc Panel

In his letter of January 10, 1972 Dr. George Low, Deputy Administrator of NASA, requested the Chairman of the Research and Technology Advisory Council, Mr. Richard E. Horner, to provide recommendations to NASA in answer to the following four questions:

(1) For the 1980's, what do you foresee as the one or two major thrusts in aeronautics?

(2) For each major thrust, what do you see as the single most important project or specific goal needed in the 1980's to support the thrust?

(3) What do the above require in advanced technology research in the 1970's in order to prepare for the major thrusts you foresee in the 1980's?

(4) What else do the above require in the aeronautics program in the 1970's in order to be in the best possible posture relative to the thrust you foresee for the 1980's?

The present report summarizes the work of a small Ad Hoc Panel set up by the Chairman of RTAC to deliberate these questions. The Panel membership consisted of:

Dr. Ronald Smelt (Chairman); V.P. & Chief Scientist
Lockheed Aircraft

Mr. Richard J. Coar, Division V.P. - Engineering
Pratt and Whitney

Dr. Antonio Ferri, Astor Professor of Aerospace
Sciences and Chairman, Department of Aeronautics
and Astronautics, New York University

Mr. Ira Grant Hedrick, Sr. Vice President, Grumman
Aerospace

Prof. Rene Miller, Slater Professor of Flight
Transporation, and Head, Department of Aeronautics
and Astronautics, MIT

Mr. George S. Schairer, V.P. - Research and New
Product Exploration, Boeing

Mr. John L. Sloop, Assist. Assoc. Administrator,
Office of Aeronautics and Space Technology, NASA
(Executive Secretary)

In approaching its task, the Panel reviewed a number of relevant recent continuing studies of aeronautical research and development such as the NASA-DOT CARD Study, recent reports to the President's Domestic Council on the aeronautical industry, and the activities of the NASA Space Council and the President's Aviation Advisory Commission. It also benefited greatly from the thoughtful responses to Dr. Low's four questions provided by individual members of RTAC and by members of the NASA Advisory Committee on Aeronautics.

It is significant that practically all of these inputs to the Panel identified the thrusts and the corresponding objectives in terms of national needs, economic or social. This is particularly true of the earlier CARD Study, and it also showed clearly in the views of individual RTAC members. The Panel therefore identified its task as being, first, to examine whether these needs have been assessed correctly and, second, to determine whether technological advances in the next decade will offer a reasonable expectation of satisfying these needs.

The second question implies the very difficult task of reconciling quite divergent views on the probable rate of technological progress in some of NASA's research areas. To augment their own views on this question, the Panel arranged a number of discussions with members of the NASA staff at Headquarters, and at the three major aeronautical research centers--Ames Research Center in California, Langley Research Center in Virginia, and Lewis Research Center in Ohio.

The first question, correct identification of anticipated needs, also gave the Panel some concern since the expressed needs were almost completely civil in nature--a similar question in the 1950's or 1960's would have led to a statement of largely military needs. To resolve this concern, meetings were arranged with the Assistant Secretaries for R&D of the Army, Navy and Air Force, together with appropriate members of their staffs. In addition, the civil needs were discussed in short meetings with the Assistant Secretary for Advanced Systems Development and Technology in the Department of Transportation. The conclusions of the Panel, summarized below, have been distilled from these many valuable meetings with men in NASA, DOD and the DOT, as well as from the Panel members' own background of experience in academic and industrial aeronautics.

2. Today Thrusts in Aeronautics

At any time in aerospace history it has been possible to identify a few major thrusts. The growth of the world's jet fleets and the development of the ballistic missile are both examples of the thrusts in the 1950's and 1960's, from the civil and military sectors respectively. As noted in the introduction, both these examples arose in response to a critical need. It is also noteworthy that the technology required was certainly not in-hand at the beginning of the thrust, but sufficient exploratory work had been done in gas turbines, swept wings, inertial navigation and other new technical areas to give some confidence that the required technologies were attainable.

A further significant feature of these thrusts, and indeed almost all past thrusts in aeronautics, is that they do not come to any clear-cut completion points; rather they continue, with steadily improving technology, establishing a permanent place in the aeronautical world. The world's jet fleets, the ballistic missile, and the space program all fall into this pattern. Individual programs are completed, vehicles and systems are replaced by later models, but the thrust continues. It is important, therefore, that we identify clearly the current major thrusts in aeronautics and recognize that they will continue, and perhaps dominate much of the technical effort in the next decade.

2.1 The Thrust Toward Greater Community Acceptance of Aircraft

This is unquestionably the most significant thrust of today, and we are unanimous that it will continue as a major preoccupation of the civil aeronautics community for the indefinite future. The subject includes both the noise and the air pollution aspects of civil aircraft, but the noise problem is by far the more important from the community viewpoint, and the more difficult from the viewpoint of the aeronautical engineer.

In the drive for reduced noise, we currently have one program which has realized a considerable measure of success--the introduction of high bypass ratio engines in the new wide-bodied transport aircraft. A second program, the retrofit of existing commercial jet aircraft to meet the noise standards of FAR 36, is under way and is expected to meet its goal in the next three to four years. It is now clear, however, that these programs must be regarded as early steps in a thrust which must reduce aircraft noise well below current standards. This fact is highlighted in the CARD Study, and is emphasized by members of the community, the airlines and the aircraft manufacturers. We believe that it is now recognized that we should not be satisfied with aircraft noise until it is reduced to approximately the prevalent noise level in urban communities. This objective is, in fact, the "specific goal" of the thrust towards noise alleviation, in the sense of Dr. George Low's second question. It does not contribute to the present discussion to debate whether this level is 10 db. or 20 db. below the current FAR 36 regulations. It is more important to recognize that the target for the '80's will be set well below the minimum which we are likely to achieve on large turbojet aircraft by an extension of our present techniques. High bypass ratios, wide blade spacings, duct absorbers, and other similar current developments are likely to reduce fan noise significantly, but we have made little impact upon the noise of the jet itself.

Further, these developments have all been largely empirical in their approach, and have given us little basic understanding of the physics of noise generation. It appears to us that the extrapolation of this thrust into the '80's will require greatly increased emphasis upon fundamental investigations of the nature of noise, whether source, dipole or quadripole in nature. We look to NASA's noise research program, and particularly to the Institute of Acoustics and Flight Sciences being set up in the Langley Research Center, to spearhead this more basic approach.

Although noise is clearly the dominant problem of aircraft, the "good neighbor" thrust of today will require greater attention to pollution aspects. The public is currently accepting today's subsonic aircraft, with the understanding that the aerospace community is developing an active program of pollution abatement near the ground. The goal of this element of the thrust should therefore be the reduction of every pollution source of present-day aircraft, including unburned hydrocarbons, NO_x, particulates, sulphur compounds and carbon monoxide. The problem of pollution during cruise has not yet received widespread public attention, except in the case of the SST, although there may be a cruise problem with the injection of water vapor and formation of clouds below 10 Km in height.

2.2 Short-Haul Air Transportation

The second thrust which we recognize today is toward the application of aircraft for shorter ranges. The present-day commercial aircraft is essentially a long-haul vehicle. It becomes economically unsatisfactory at ranges below about 200 miles, and it is challenged by all other modes of transportation--the private automobile, the bus, and the train--at distances below about 150 miles. It takes many forms: the air taxi services developed around aircraft such as the de Havilland Twin Otter; the prototype STOL commercial transport aircraft being built in a number of countries; the NASA QUESTOL program and the airlines' investigation of reduced takeoff and landing to permit operation into existing smaller airports. This drive is accompanied by a parallel series of military programs; indeed, the Department of Defense has been experimenting with V/STOL prototypes for almost two decades. The Vietnam War demonstrated decisively the value of the helicopter--the only V/STOL currently in large-scale operational use.

We can expect this double interest, civil and military, to develop into a major thrust in the 80's. We believe, however, that it will change direction significantly in the course of the next decade, and we have therefore identified a major new thrust, into VTOL operation as distinct from the present STOL interest, which will characterize the next decade. The nature of this change is discussed in detail under Section 3.2 below.

3. The New Major Thrusts of the 1980's

The present-day thrusts discussed in the last section are of critical current importance to the aeronautical world, and as such they have been highlighted in the CARD Study. Furthermore, as also stated earlier, there is no doubt that their impact will have a lasting effect on the progress of civil aeronautics, continuing into and beyond the 80's. Nevertheless, the Panel believes that its task should be to identify thrusts over and above our present concerns, which may assist NASA in its identification of R&D programs during the next decade.

The many inputs to Panel discussion identified several areas where a significant step forward in aeronautics may occur during the 80's. The Panel has identified only two of these as major thrusts; these are discussed in the two following sections. For completeness we have also summarized our thoughts regarding the other candidates which have been proposed to us.

3.1 Higher Speed Long-Haul Transportation

Long-haul passenger transportation is the backbone of the air transport industry. The airplane has no effective competitor for distances over a few hundred miles, and it is economically most productive at the longer ranges. This is in clear contrast to the short-haul application of aircraft, where the airplane is competing with other methods of transportation--the automobile and the railroad, and decisions are also influenced by a number of social factors. The aircraft and airlines of the U.S. dominate the long-haul market; at the present time over 75% of the aircraft in use throughout the world on long-haul operations are manufactured in the U.S.A.

In responses received by our Panel assessing the probable thrusts of the 80's, there was an almost unanimous selection of the future higher speed long-haul aircraft as a major item. This selection was invariably accompanied by concern that the U.S. may be losing its current leadership in the long-haul market in consequence of the threat of the French-British Concorde and the Russian TU-144 supersonic aircraft. The direct operating cost of this first generation of supersonic transports is presently higher than for subsonic transports. However, the elasticity of demand to an increase in speed is well-known--the airlines have comparable operating experience in the premium fares imposed during the introduction of the jet transport--and it appears that the higher load factors which the supersonic transports can command will offset the initial disadvantages of direct operating costs. Furthermore, present advanced technology suggests that such costs will gradually become competitive, primarily because of improvements in engine performance and the possible introduction of variable cycle engines. For all these reasons, there is a recognition that the supersonic transports will slowly take over the premium long-haul routes from the present generation of wide-bodied subsonic jet aircraft. The competition between the subsonic and supersonic aircraft will, of course, be keenest on the routes across the North Atlantic, where the possible limitation of the supersonic aircraft due to sonic boom is not significant.

It is already recognized by the aeronautical world that the first generation of supersonic transports is not ideal for this purpose. The further development of supersonic transports must aim at acceptable takeoff and landing noise levels, must improve the economics, and must give an extra margin in operating range to cover most of the trans-Atlantic routes. Our competitors recognize the potential improvements which must be made, and are already planning the second-generation "Super Concorde". Their operating experience for several years with the first-generation SST's, and their consequent lead in the technology, presents a formidable challenge. In addition, it is becoming clear that future developments in such aircraft will be required to provide even longer ranges, as the trade routes of the world change and particularly as the trans-Pacific passenger traffic increases. Indeed, in the late 80's it appears that this change in world trade will require ranges up to 7,000-8,000 miles in passenger service.

In presenting this thrust to supersonic long-haul air transportation as the major thrust in aeronautics for the 80's, the Panel believes that the need is clear, and that ultimate ranges of 7,000-8,000 miles appear to be within reach of our technology in the late 80's.

However, it appears to us that the erosion of U.S. supremacy in this market would be much too severe for effective recovery if there were no competitive U.S. product for the next 15-20 years. It therefore appears that the thrust toward higher speed long-haul transportation will be characterized by two distinct goals--one short-term and the other longer-term.

The short-term objective can be simply stated as the need to develop aircraft which show a sufficient improvement over the first-generation SST's, and also over the possible extensions of these into "Super Concordes", to compete successfully for all of the trans-Atlantic routes, which will still be the routes of highest traffic density for the next decade. We see these aircraft as coming into operation in the late 70's or early 80's, depending upon the length of time required for the American public to recognize completely the consequences of the recent SST cancellation. Its development will require the combination of our wide-bodied aircraft structural technology with the special requirements for flight at a Mach No. of around 3 or 3.5. It will probably use conventional gas turbine fuels and titanium construction (although one Panel member insists that skin cooling is already a technically feasible competitor). The achievement of a satisfactory supersonic transport depends greatly upon engine development including reduction of airfield noise and lower cruise specific fuel consumption. Technological development for this goal should, in fact, concentrate heavily upon the propulsion unit and its integration with the airframe.

The longer-term goal is the development of the full potential of supersonic (or hypersonic) aircraft for economically acceptable flight at ranges of 8,000 miles, thus satisfying the longer-term needs for passenger transport. It has been recognized for a number of years that these longer ranges can be attained by increasing speed, and a number of alternative concepts have been put forward--booster-glide, ballistic or hypersonic cruise aircraft--largely utilizing technology from the missile and space programs. Recent fairly detailed comparative assessments by NASA's Advanced Concepts and Missions Division imply a clear advantage of the hydrogen-burning hypersonic cruise aircraft. This will probably cruise at a Mach No. between 6 and 8, and can achieve a very acceptable DOC of 2¢-3¢ per seat mile for ranges up to 8,000 n. mi. It is important to emphasize the extent to which such a development follows naturally from our present space technology, since the U.S. has a clear lead over the rest of the world in these technical areas. The problems of aero-dynamic heating at high speeds, the handling of liquid hydrogen and its use as a fuel are all directly applicable. Several communications to the Panel recognized the similarity in technology required for the long-haul hypersonic transport aircraft and that required for a recoverable booster for the shuttle. Indeed, if the present solid rocket first stage for the shuttle is ultimately replaced during the 1980's by a second-generation air-breathing stage, capable of taking off and landing from many locations and also of carrying untrained passengers, this vehicle might itself prove to be a viable transport aircraft.

For both short-term and long-term goals of the thrust to high speed long-haul transportation, the Panel emphasizes propulsion technology and engine-airplane integration as the most important area for NASA attention. All transport aircraft will be required to satisfy standards for extremely low-noise takeoff and landing, and the technical challenge of combining this requirement with good cruise efficiency is obvious. In addition, the engine inlet and jet nozzle presented significant challenges to the developers of the Concorde and will be an even greater problem as the speed increases. NASA and the U.S. aircraft engine developers will probably be compelled to develop dual mode engines to satisfy the conflicting takeoff and cruise requirements.

The problems of cooling of the structure, and particularly, the technology of fuel cooling of the aircraft skin, require NASA attention. A further structural problem is presented by the aeroelastic characteristics at high Mach numbers. The aerodynamics of supersonic and hypersonic flight have already received quite a lot of attention in the NASA Centers but there is a need to point this work specifically at the problems of the transport aircraft. This is probably best done by a number of configuration studies, conducted in cooperation with the aircraft industry, which will reveal specific technological problems such as stability shift, transonic drag, and high speed L/D.

Although the above discussion has stressed the application of supersonic transports to over-water routes, the additional flexibility of over-land flying would be very desirable, if the sonic boom could be alleviated sufficiently. This presents the aeronautical world with a difficult technical challenge, to which NASA and others have already responded with schemes for reduction of boom strength. It also presents DOT-FAA with a regulatory problem which impacts significantly on the engineer's incentive to reduce the boom. Unlike FAR 36 and its probable successors regulating airfield noise, which specify the maximum permissible noise in terms which constitute a challenge to the power plant developer, the boom restrictions are currently stated in absolute terms--no over-flight of supersonic aircraft even if the designer can reduce the dimensions of the boom to that of the bark of a dog in a padded doghouse. It is evident that we require some assessment of the acceptable level of similar noises--barking, hand-clapping or thunder--to serve as a standard against which to measure improvements in the boom of a supersonic aircraft. Without such standards, there is no incentive for improvement of technology in this area, since it is generally recognized that the boom cannot be reduced to zero.

The same comment applies to the possible pollution contribution of supersonic aircraft during cruise. Fortunately, DOT and NASA have already initiated work on this problem, and DOT's Climatic Impact Assessment Program should provide in the next one or two years a technological basis upon which design criteria for the products of combustion of the power plant can be constructed.

Throughout the above discussion of higher speed long-haul transport, the thrust has been examined entirely from the viewpoint of civil transportation. It should be noted, however, that an Air Force planning study, "Beyond the Horizon", conducted in 1966, recognized the advantage to the Air Force of longer-range, higher speed operation than is possible with their present generation of subsonic military transports. Our short discussion with the Air Force Assistant Secretary for R&D and his staff showed that this interest in hypersonic long-haul transportation still exists.

3.2 The Thrust Toward Short-Haul Air Transportation

During the next decade, a major thrust will be directed toward the improvement of short-haul transportation using a common carrier air system with common carrier ground transportation providing a convenient system for microcollection and distribution to the air carrier terminals. Although the specific goals and projects which support this broad thrust into short-haul transportation will be many and varied and will involve Federal, state, and municipal agencies, NASA's major role in support of the thrust will be to develop the required technology for a new generation of STOL and VTOL vehicles and their supporting systems. As stated in Section 2.2, STOL aircraft technology is part of a current thrust and therefore will not be discussed further here.

Studies to date indicate that present technology could permit the development of a high-speed air transportation system which requires no runways and hence could access directly the city and suburban centers. A major thrust for the next decade will be directed towards development of these aircraft. They will have a VTOL capability, cruise speeds of the 350-400 miles per hour, low noise levels below 70PNdB at airport boundries, be non-polluting and capable of all-weather operation with a high dispatch reliability. Such a system could be developed to operate effectively over intra-city routes with a high frequency, relatively small capacity (50-100 passenger) economic service providing complete suburban area transportation. The VTOL system will also provide access from every point in the area, including the city center, to the central airport from which the medium and long-haul aircraft operate, thus solving the problem of ground congestion in accessing large metropolitan air terminals. It is expected that this transportation system could well change our entire concept of urban complexes. The ability to travel 30 miles comfortably in six minutes at 10¢ a passenger mile would permit the separation of living and manufacturing from the central business core of the city, allowing a diversification of metropolitan functions in several rings or areas extending several tens of miles into the countryside and connected by such a high-speed transportation system.

The high investment costs which experience has indicated are necessary for new rapid ground transportation systems and the lack of flexibility of such systems with their fixed rights of way will probably make them non-competitive with air except for very short distances in very heavily built-up urban areas such as the core city center. However, the problem of accessing the city and suburban VTOL terminals will still require some form of surface or subsurface transportation.

A further aspect of this thrust therefore must be the development of a rational total transportation system involving both common carrier air and common carrier ground transportation over very short distances in the core city, with individual transportation systems less costly than the conventional automobile for suburban areas. Although it is not expected that any common carrier system will ever be able to compete for the majority of travel purposes with the comfort and convenience of a car, it is certainly true that improved mass transportation over the ultra-short-haul distances from 10 to 100 miles will provide an alternative mode attractive to many who cannot afford the luxury of individual transportation or who prefer a faster means of short-distance travel than can be provided by the automobile operating over congested urban and suburban road systems. The probable model split and methods of providing these alternative transportation systems can only be determined from careful systems analyses using the evolving disciplines of transportation analysis.

In essence, then, the present thrust toward STOL aircraft development for civil short-haul transportation is expected to broaden during the next decade, with VTOL civil transportation coming to the fore. The VTOL aircraft will attain a further importance because of the very high interest of both the Navy and the Army in VTOL applications. The Army, Navy, and Marines have depended upon the helicopter for a number of years, and the Army is taking the lead in its current development and application. The Panel was very favorably impressed by the joint arrangements which have been set up between NASA and the Army to advance the state of the art in rotorcraft.

The Navy's continuing interest in VTOL aircraft has been greatly increased recently in consequence of the changed role which is envisaged for carriers vis-a-vis smaller ships. Air access to these smaller ships, the new concept of a sea control ship, and the definition of missions requiring longer ranges of endurance than are possible with current helicopters are among the factors which impel the Navy to press for a significant forward thrust in VTOL technology. The VTOL development possibilities fall into two classes: the rotor vehicles, such as the tilt rotor aircraft and the compound helicopter; and the jet lift vehicles, such as the lift fan and direct jet lift, the latter comparable with the present Harrier aircraft. The technology for both types needs development to permit higher speed, longer range application; in this respect the Navy and Marine Corps requirements parallel closely those of the civil VTOL aircraft described earlier.

The technologies involved in these aircraft developments are well-known, but it is appropriate to single out a few special problems here. All rotor vehicles present aeroelastic problems, and the structural design and material selection bring in the rapidly evolving technology of crack propagation, fatigue, and structural lifetime. Aerodynamic problems include blade stall and overcoming speed limitations (e.g., by use of circulation controlled rotor) and the special troubles of recirculation, with the danger of ingestion of dirt and sand. A quantum improvement in VTOL aircraft is strongly dependent upon improved propulsion and NASA needs to develop the technologies for these improvements. The main problem of the propulsion unit, for civil application, will be to reduce the noise level on takeoff and landing to an acceptable level for the urban locations in which the aircraft must operate. It is of interest to note that the same problem of quiet operation, particularly with rotorcraft, characterizes some military applications. Finally, the VTOL machine will involve the designer in new problems in the design of gears, transmissions and bearings. This is a somewhat neglected field in aeronautical technology since the passing of the piston engine and propeller, and NASA should lead in the research aspects of the subject.

4. Other Candidates, Not Selected as Major Thrusts

The two major thrusts discussed in Section 3 above were selected by the Panel on the basis of the Panel's own views, augmented by majority recommendations from the many sources which we consulted. A number of other potential candidates were endorsed by several sources, and we have thought it appropriate to list these runners-up. They serve to emphasize that our selection of two major areas in Section 3 does not imply a relaxation or neglect of the technologies appropriate to these other areas. Indeed, much of the technological advance in aeronautics in the next decade will be broadly applicable, and will probably serve to make some applications possible which are only marginal at present. For example, the present trends in new structural materials, notably the composites, will apply across the board. The greater use of electronics in aircraft, both in the development of control configured vehicles and in the evolution of more efficient, cheaper, air traffic control systems, is another example of an across the board development.

Four candidates which will grow in importance, and which require NASA's technology as a part of their growth, are as follows:

4.1 Transonic Aircraft

The present generation of subsonic transport aircraft can of course be steadily improved by the application of the technologies just listed, and also by some special concepts such as the supercritical wing. The Panel did not elevate the evolution of future transonic aircraft to be a major thrust, primarily because it believes that the introduction of the supersonic aircraft is a more significant development from the point of view of the airlines, and a more demanding development from the point of view of NASA technology. It is important to recognize, however, that transonic aerodynamic technology appears in a number of the concepts which we have identified under our major thrusts. For example, the supersonic transport must have a sufficiently low drag in the transonic range; and the rotorcraft could benefit by the application of supercritical wing technology to rotor blade tips. Additionally, military aircraft would benefit greatly from improvements in maneuverability performance, and buffet boundary of military aircraft in the transonic speeds regime.

4.2 Air Cargo Aircraft

A number of replies to Dr. Low's questions in Section 1 stressed the growing importance of air cargo. It is true that air cargo operations have reduced considerably in cost with the advent of the larger aircraft, so that for a number of special cargoes the overall cost balance, including the cost of inventory in transit, the reduction of pilferage, etc., can compare favorably with other cargo transport modes. We have not listed this as a major thrust, however, since we do not have any evidence that the potential cost per ton mile of air cargo (around 15¢-20¢) can be reduced to be comparable with that of truck freight (around 5¢). When the additional advantage of door-to-door operation of trucks for many cargoes is superposed on this, we believe that the air cargo market will show a steady and continuing increase, rather than a recognizable sudden major thrust.

4.3 General Aviation Aircraft

The possible development of the general aviation field into a more major part of the aeronautical world was brought forward in a number of discussions. A number of writers have projected transportation requirements forward to the point when individually-owned aircraft will supersede the automobile as a means of personal transport. The Panel believes that the steps required to achieve this evolution, notably in case of control, vertical takeoff and landing, and adequate economical air traffic control devices, are so far away that we should not identify it as a major thrust for the next decade or more.

4.4 Remotely Piloted Vehicles

This military development is difficult to assess as a future major item. In the absence of a clearer picture of the future potential to the Services, we have elected not to highlight it in the present report. In part, this is due to a recognition that the major developments involved are in the electronics of control, communication and sensing. These appear to be more appropriate to the research programs of the Services than to NASA.